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SETTING, GROWTH AND MORTALITY OF *CRASSOSTREA VIRGINICA* IN A NATURAL MARSH AND A MARSH ALTERED BY A HOUSING DEVELOPMENT [1]

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ABSTRACT

In February 1969, asbestos plates for collecting oyster spat and partitioned trays containing eight size groups of juvenile oysters were placed in (1) a dead-end canal in a housing development created by dredging, bulkheading, and filling part of a coastal marsh; and (2) a dead-end bayou in an unaltered part of the same marsh in West Bay, Texas. The plates and juvenile oysters were then monitored periodically for the next 12 months.

Temperature, salinity, dissolved oxygen, total phosphorus, inorganic phosphate-phosphorus, Kjeldahl nitrogen, nitrite, turbidity, pH, CO_2, total alkalinity and carbonate alkalinity were monitored in the water at both locations. Eight of the above variables were compared to the growth and mortality of the juvenile oysters.

Spat set from late May until October 1969, with the greatest settlement in September. Although never heavy, setting was 14 times greater in the marsh than in the altered area.

Juvenile oysters grew faster in the marsh than in the altered area. Within each site the individual size groups increased in mean length at similar rates. The average increase in length was 52 mm/year in the natural marsh and 33 mm/year in the altered area. The average increase in weight was 136 g/year in the natural area and 86 g/year in the altered area, and was greatest in the largest size group in both areas.

Mortality rates of juveniles were similar among all size groups in the development and greatest among the largest size groups in the marsh. The annual rate of mortality averaged 91% in the altered area and 52% in the natural area. Dermocystidium marinum *was not detected in three spot checks during June, July and August.*

Greatest differences in spatfall, growth and mortality between areas were in the summer when dissolved oxygen was lower in the narrow dead-end canals in the altered area. Also several plankton blooms followed by very low oxygen and then fish kills occurred in the canal during the summer.

INTRODUCTION

One and three-tenths million kilograms of oyster meats valued at $1.3 million were harvested from the Galveston Bay system in 1968, totalling 86% of the Texas oyster harvest (Farley, 1969). This oyster harvest from this bay system was taken in less than half of the total water area, however, because of harvesting restrictions relating to fecal pollution (Fig. 1). If the amount of sewage discharge into the system increases, more of the bay area will be closed to commercial harvest, and alternate methods and areas will be needed to supply the demand for oysters.

[1] Contribution No. 312 from the National Marine Fisheries Service Biological Laboratory, Galveston, Texas.

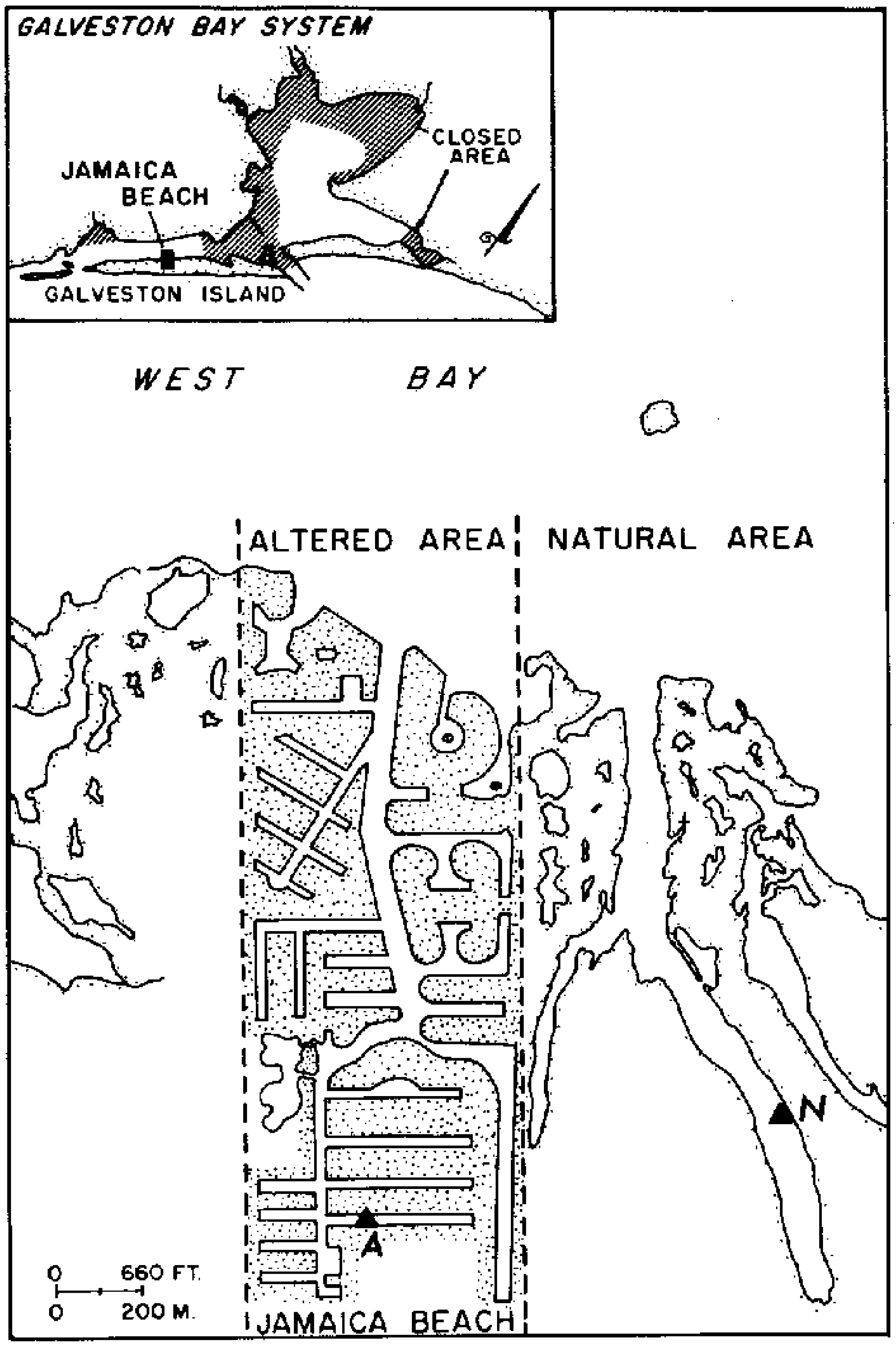

FIG. 1 *Areas of the Galveston Bay system closed to shellfish harvest in 1969-1970 because of pollution (Texas State Department of Health, 1969), and locations of sampling stations in West Bay, Texas.*

Many coastal areas such as West Bay, Texas (Fig. 1), though meeting public health standards for oyster harvest, do not produce large quantities of oysters because of environmental limitations. Production of oysters in the open part of West Bay is low, probably because high salinities provide excellent habitat for the oyster drill, *Thais haemastoma,* and the fungus parasite, *Dermocystidium marinum.* Salinity is lower in many of the bayous adjacent to the bay, however, and they would probably support sizable populations of oysters if sufficient substrate were available.

Large areas of shallow bay and marsh are being developed for housing sites along the Gulf coast. This type of alteration involves dredging, filling and bulkheading. Bulkheads in the developments provide substrate for attachment of oysters and are potentially useful for intensive oyster culture because (1) the water is deeper than adjacent natural areas, (2) culture techniques could be applied without seriously interfering with other uses, (3) the waters should remain unpolluted in the new developments because of requirements for treatment of sewage and (4) the areas are easily accessible by boat or automobile.

The general objective of this study was to determine the feasibility of utilizing bulkheaded canal areas for economic oyster production. Specific objectives were (1) to compare the setting rates of oyster spat and the growth and survival of juvenile oysters in a marsh area altered by channelization and bulkheading with those in an undisturbed marsh and (2) to determine how juvenile growth and mortality rates vary in relation to the environmental parameters affected by the habitat modification.

STUDY AREA AND METHODS

Jamaica Beach, located on the Galveston Island shoreline adjacent to West Bay (Fig. 1), was selected for study because it is one of the largest housing developments on the Island, has the most complex canal system of any of the developments, is bordered by natural marsh areas and is located in an area of West Bay approved for oyster harvesting by the Texas State Department of Health (1969).

Sampling station "A" was established in a dead-end canal adjacent to a bulkhead in the development and station "N" was established in a natural bayou east of the development (Fig. 1). Water depth (mean low tide) was 1.1 m at A and 0.8 m at N. Many adult oysters were attached to the bulkheads at station A, and a small reef was located within 50 m of station N.

Twelve hydrological variables were monitored at each station during alternate weeks from the oyster mortality and spatfall checks, from 20 March to 15 November, and monthly from December to February by Pullen, Proctor and Trent (MS.)[2]. Water temperature was monitored continuously by a recording thermograph at each station and salinity was determined whenever the oysters were checked in addition to the determinations made during the hydrological study.

Three pairs of asbestos plates were suspended in the water at each station to determine the rate of oyster spat set. Each plate was 12.7 cm^2 and 0.3 cm thick and had one smooth surface. The plates

[2] Pullen, E. J., R. R. Proctor and L. Trent. (MS.). Environmental differences between a natural estuarine area and a similar area altered by a land-fill housing development.

were seasoned in sea water for 2 weeks and scraped clean before initial use. The individual plates of a pair were placed horizontally, with smooth surfaces facing each other, 2.5 cm apart on a wooden rack suspended vertically from a tripod field structure. Each pair of plates was located 0.3 m below the previous pair. The frame rack was suspended at each station so that the upper pair of plates was located at mean low water. The plates were replaced with clean ones at 2-week intervals. Spat attached on the central 100 cm^2 area of the smooth side of each plate were counted with the aid of a binocular microscope; this count was used as the unit of observation.

The growth rates of juvenile oysters were determined using unattached oysters placed in two trays near the spat collectors in each area. The trays were standard 81 x 46 x 10 cm polyvinyl-coated (laboratory cart) baskets similar to baskets used in oyster mortality studies by Hofstetter, Heffernan and King III (1965). Each tray was lined with 1.3-cm mesh galvanized wire screen and was partitioned with strips of screen into 18 squares (13 x 13 cm). Juvenile oysters used were dredged in February 1969, from an oyster reef near the middle of Galveston Bay and were from a late summer spawn in 1968 (R. P. Hofstetter, personal communication). The oysters were separated from the dead shell, cleaned of major fouling and sorted into groups having shell length ranges of 5 mm (25-29, 30-34, 35-39 mm, etc.). The oysters were placed in running sea water for 2 weeks so that most of the mortality resulting from handling occurred prior to initial measurement and placement in the field.

Before placing in the trays, total length to the nearest millimeter and the weight to the nearest 0.1 g of each oyster were recorded. Seventy-two oysters were placed in each tray. Four oysters in the following size ranges were placed in the number of compartments indicated in parentheses: 25-29 mm (1); 30-34 mm (2); 35-39 mm (3); 40-44 mm (3); 45-49 mm (3); 50-54 mm (3); 55-59 mm (2); 60-64 mm (1). Within each tray, the 18 groups of four oysters each were placed randomly in the compartments.

The trays were placed 2 ft apart on frames positioned 0.3 m below mean low water at stations A and N. Total length was recorded for each oyster once per month and weight was recorded every 2 months. The oysters were lightly washed prior to measuring and major attached fouling organisms were carefully removed prior to weighing. Whenever the oysters were removed for measuring, the trays and partitions were cleared of major fouling and algae. Excessive algae was also removed during each mortality check.

The oysters were examined every 2 weeks to monitor mortality. Dead oysters were replaced with live oysters having about the same shell length and a similar shell configuration until the supply of reserve oysters held in trays at each station was exhausted. We assumed that the bias resulting from a lack of growth of each dead oyster for a period of, at most, 2 weeks would not appreciably affect our results, and that the variability in weight was random between the replaced oyster prior to its death and the reserve oyster used to replace it. All dead oysters were replaced until 20 August in the altered area and 24 September in the natural area. Not all of the dead oysters were replaced subsequently. The number of oysters remaining in the trays, therefore, diminished after these dates. The original 144 oysters and their substitutes in each area had diminished to 119 and 45 at the natural and altered sites, respectively, by the end of the study on 18 February 1970. Annual mortality rates were computed by converting all the 2-week rates to instantaneous rates, then totalling and converting the sum to annual rates.

The possibility of infection of the juveniles with *D. marinum* was checked by thioglycollate culture of the flesh (Ray, 1966) of dying oysters which were recovered while still relatively undecomposed.

HYDROLOGY

Eight of the 12 hydrological variables monitored showed apparent seasonal or areal differences (Fig. 2). Temperatures were similar between areas but followed the typical seasonal pattern. Salinity was low in the spring, rose rapidly in June, and remained above 23‰ for the rest of the period

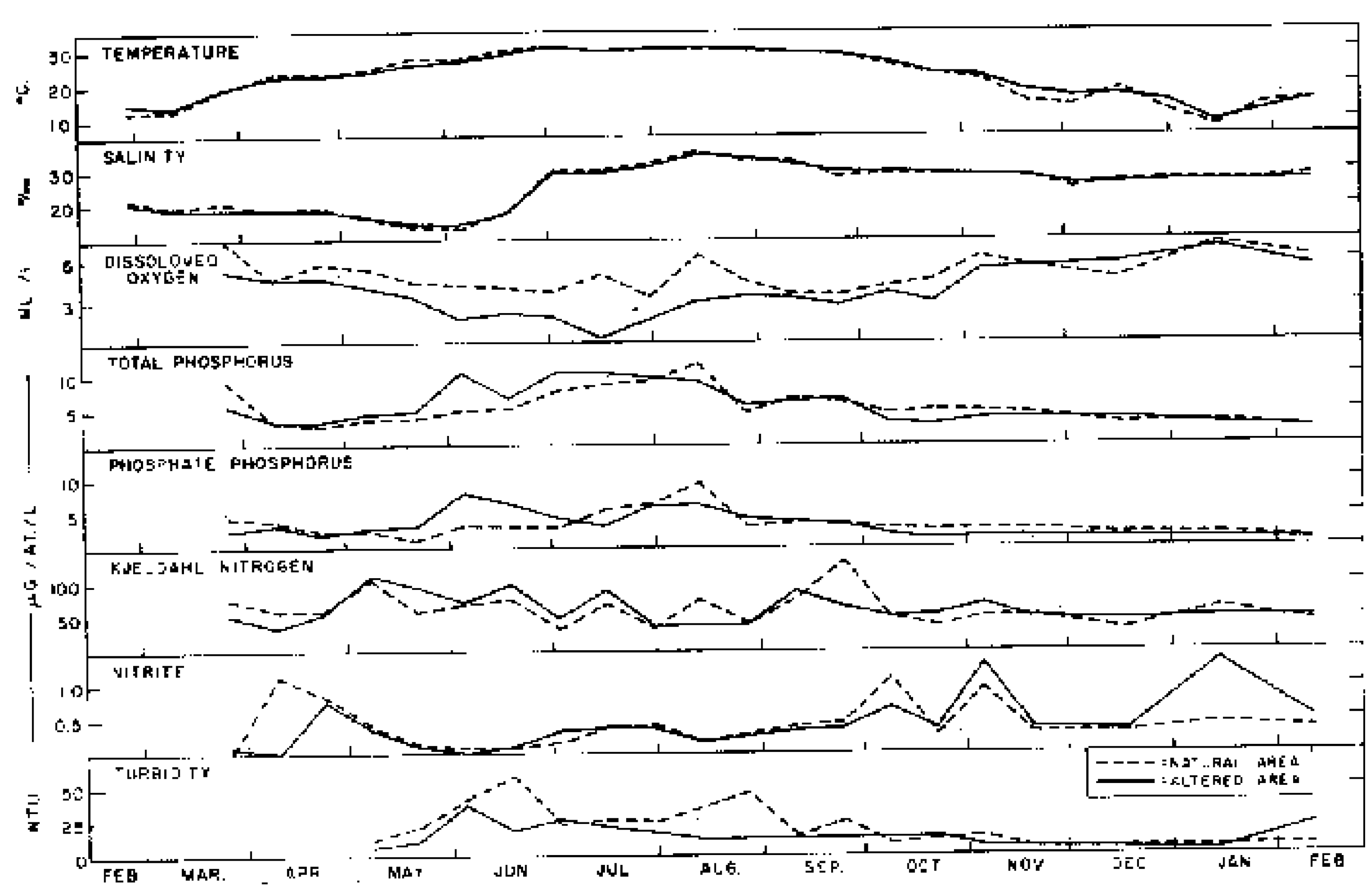

FIG. 2. *Comparisons, between the canal and bayou, of the values of eight hydrological variables by date and area.*

in both areas. Dissolved oxygen was considerably lower in the canal than in the marsh during the late spring and early summer. Total phosphorus and phosphate-phosphorus values rose in late spring in both areas and maintained higher levels in the altered area than in the natural area during this period. Kjeldahl nitrogen levels fluctuated erratically and averages were highest during spring and summer in both areas. Nitrite levels were lowest during late spring and summer in both areas. The waters were more turbid during spring and summer, and turbidity was higher in the natural area. Total and carbonate alkalinity, pH and CO_2 values were similar between dates and areas.

SPATFALL

Only 197 spat attached to the central 100 cm² of the smooth surfaces on the suspended plates during the study. Over three-fourths of these spat set on the plates with the smooth surfaces facing down. Setting occurred from 28 May to 1 October in the natural area and from 6 August to 1 October in the altered area, with the peak spatfall in both areas being in late September (Fig. 3). In a previous study in West Bay, Hopkins (1931) observed the first spat settlement in the middle of May. He noted that setting was irregular and took place during short time periods. More recent studies in Galveston Bay showed that spatfall started in late May or early June in 3 of 4 years and in April the other year (Hofstetter, 1960, 1963). During 1969, in Galveston Bay, peak setting of oyster spat was observed in July, with a second setting period observed in September-October (R. P. Hofstetter, personal communication). Our peak spatfall occurred during this second setting period observed in Galveston Bay.

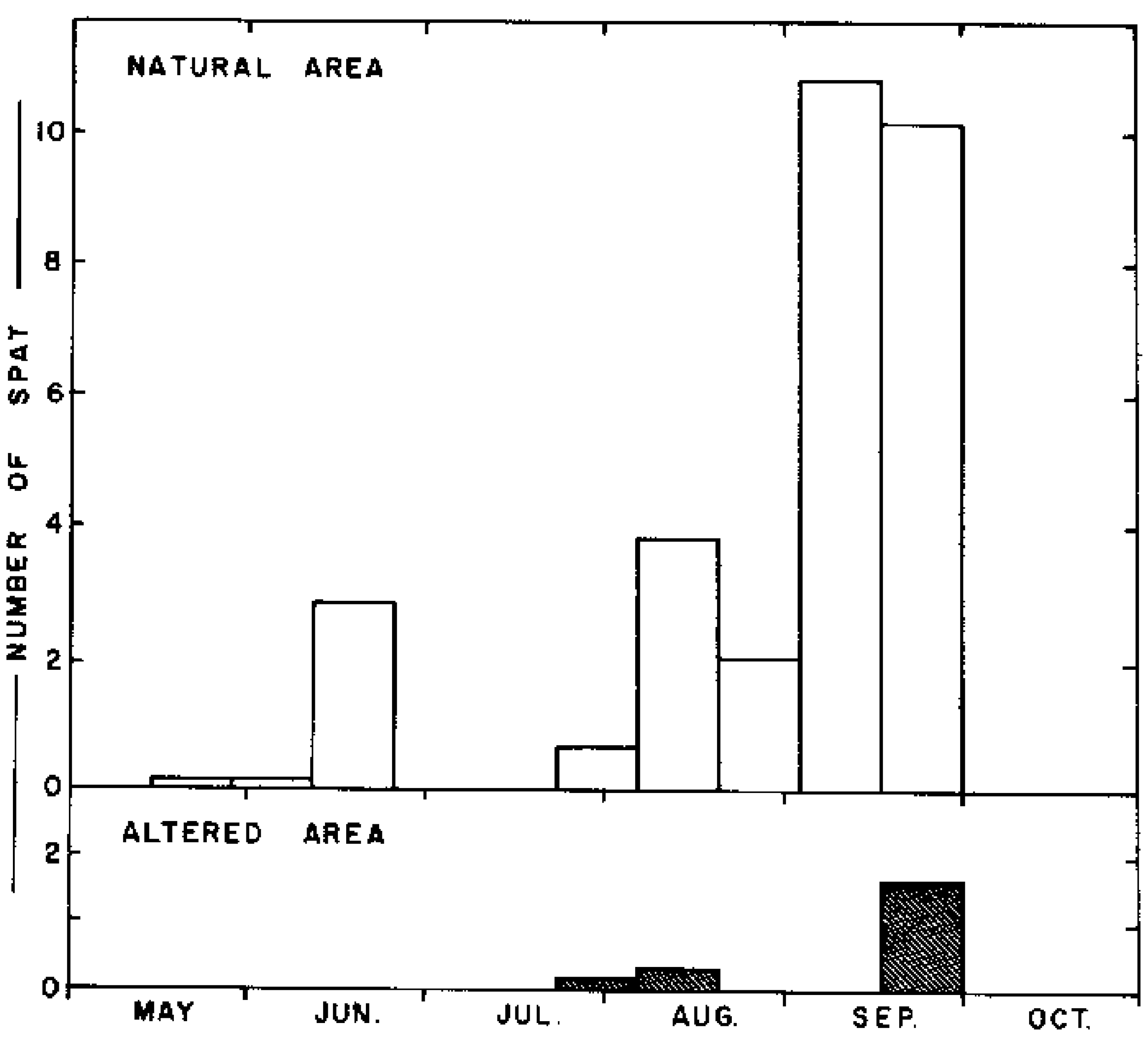

FIG. 3. *Mean number of spat per plate by date and area.*

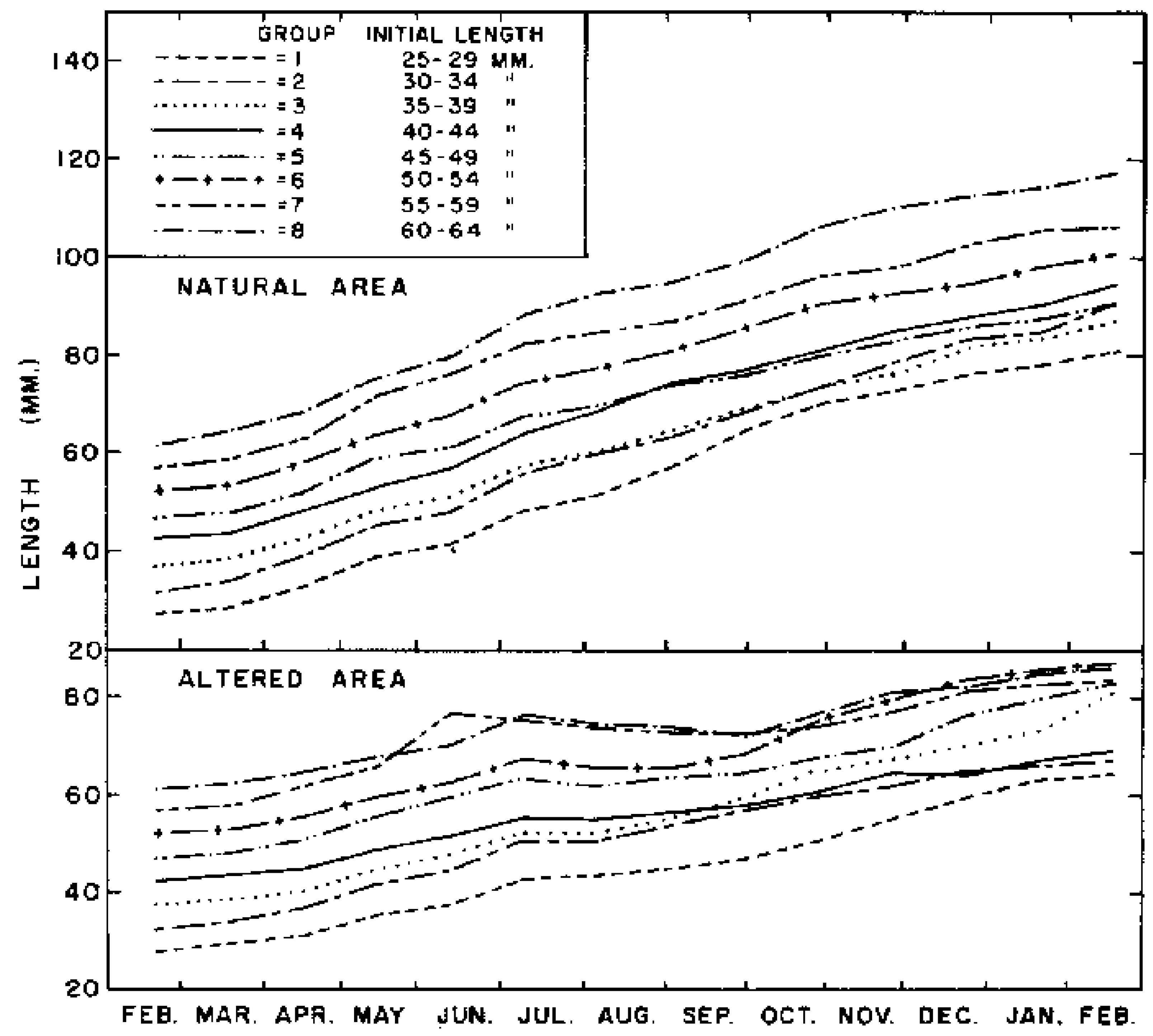

FIG. 4. *Mean lengths of juvenile oysters by size group, date and area.*

Spatfall in the natural area was about 14 times greater than in the development. The peak spatfall in the natural area, however, was lower than Hofstetter (1959) observed during a light spatfall year, 1958, on the commercial oyster reefs in Galveston Bay. Spatfall greater than a trace occurred over a time period so short that attempts to establish correlations between spatfall and hydrological variables would be meaningless. All setting did occur, however, when temperatures averaged above 25°C. (Fig. 2) and this result was similar to previous data reported by Hopkins (1931) in another area of West Bay.

GROWTH

Growth in length was compared among eight size groups of juvenile oysters for each area (Fig. 4) and between areas with size groups combined (Fig. 5). Growth in the natural area was almost linear and was similar among size groups. In contrast, growth was depressed from July through September in the altered area, especially in the large size groups. The average increase in length (sizes combined) for the 12 months was 55 mm in the natural area and 32 mm in the altered area, or 72% greater in the natural area. The oysters at the end of the study were about 18 months old and averaged 87 mm. Growth in

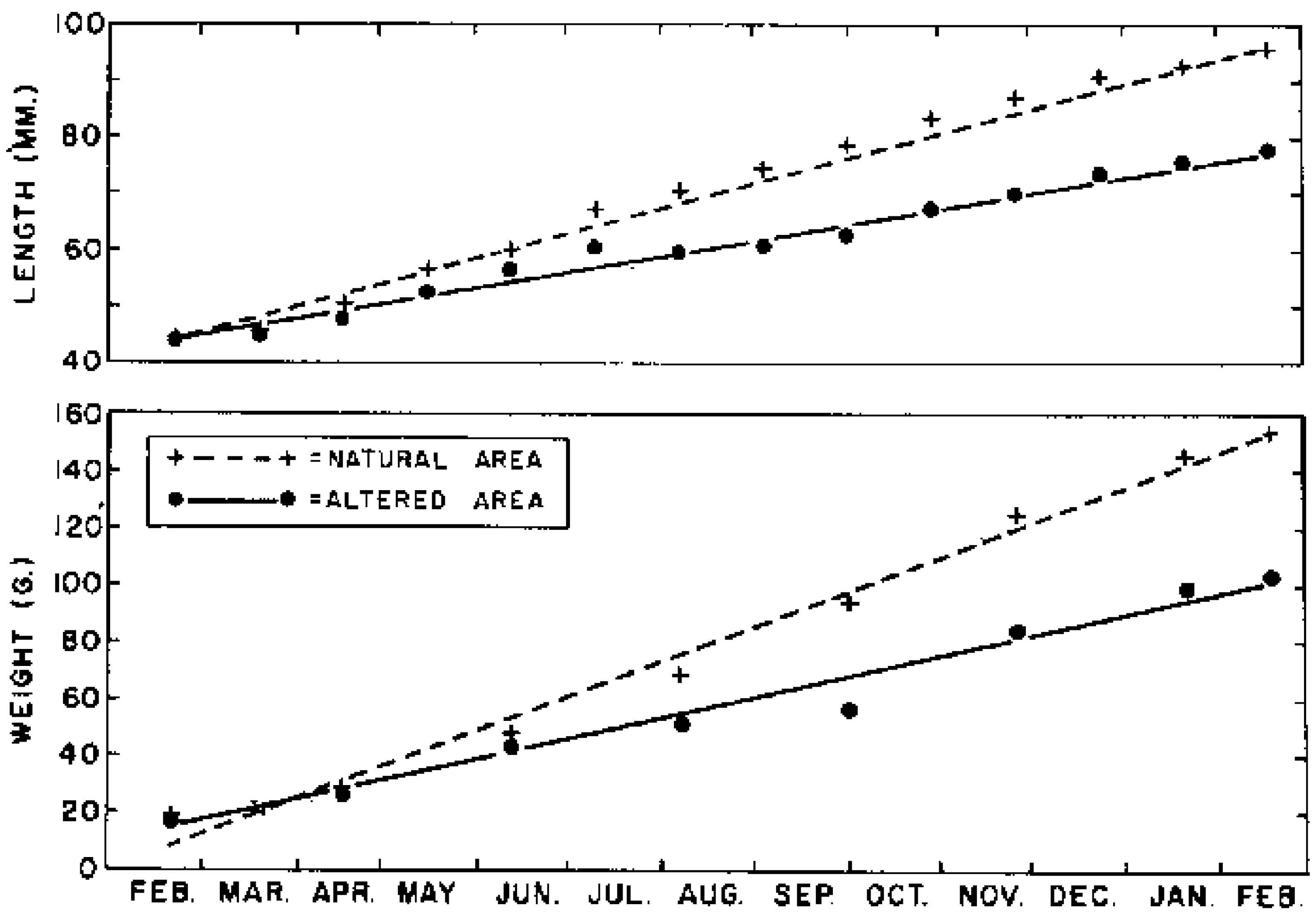

FIG. 5. *Mean lengths and weights of juvenile oysters (size groups combined) by date and area.*

length of juvenile oysters was significantly and positively correlated to temperature in the natural area and to dissolved oxygen in the altered area (Table 1).

The average increment in length observed in the natural area was greater than the maximum reported by Hofstetter (1963) for oysters from commercial reefs in Galveston Bay. In studies of oysters in trays, however, he observed growth rates similar to ours (R. P. Hofstetter, personal communication). Menzel (1955) reported that oysters averaged 75 mm 10 months after setting at Aransas Pass, Texas.

Growth in weight was compared among the size groups by area (Fig. 6) and between areas (Fig. 5). Unlike length, weight increased at a greater rate in the larger oysters in both areas. Similar to length increments, the rate of weight gain was depressed during June-September in the altered area. This depression was most pronounced in the largest oysters. The average increase in weight (sizes combined) was 136 g in the natural area and 86 g in the altered area, or 58% greater in the natural area.

MORTALITY

Annual mortality rates of juvenile oysters were similar among size groups in the altered area, ranging from 82.6-94.0%, whereas in the natural area there was much variation among size groups, ranging from 31.6-77.9% (Fig. 7). Mortality was greatest during the warmest months in

TABLE 1. *Correlation coefficients (r) between hydrological variables and length increments and 2-week mortality rates of juvenile oysters in the natural and altered areas in West Bay, Texas.*

Hydrological variable	Area	Length increment		Mortality rate	
		df	r	df	r
Temperature	Natural	11	0.59[a]	24	0.61[b]
	Altered	11	-0.09	23	0.69[b]
Salinity	Natural	11	-0.06	24	0.76[b]
	Altered	11	-0.40	24	0.70[b]
Dissolved oxygen	Natural	11	-0.41	19	-0.37
	Altered	11	0.56[a]	19	-0.51[a]
Total phosphorus	Natural	11	0.11	19	0.65[b]
	Altered	11	-0.39	19	0.41
Phosphate-phosphorus	Natural	11	0.07	19	0.63[b]
	Altered	11	-0.35	19	0.29
Kjeldahl nitrogen	Natural	11	0.33	19	0.03
	Altered	11	0.26	19	-0.01
Nitrite	Natural	11	0.06	19	-0.08
	Altered	11	0.06	19	-0.13
Turbidity	Natural	11	0.32	19	0.23
	Altered	11	0.13	19	0.05

[a] 95% confidence

[b] 99% confidence

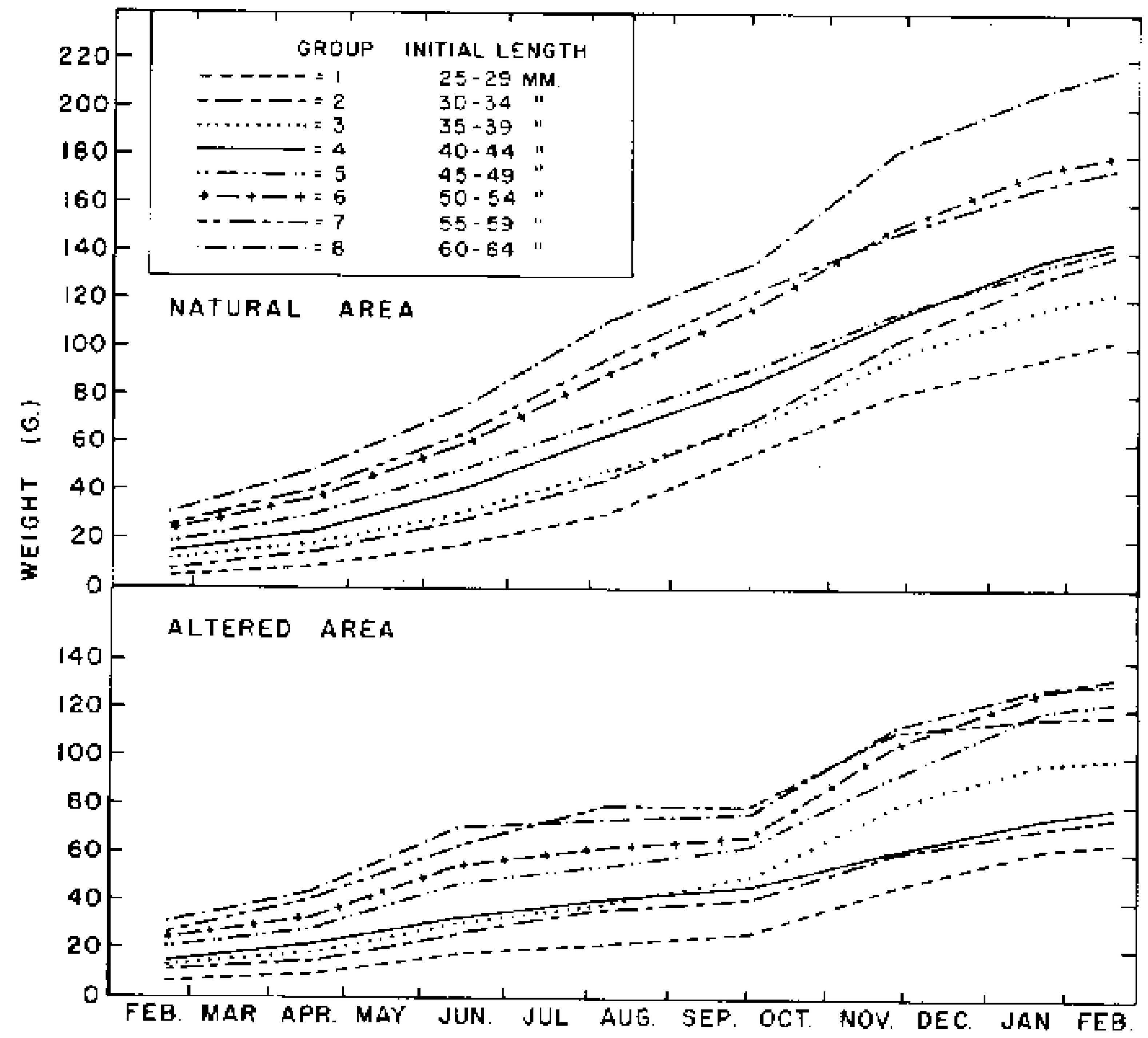

FIG. 6. *Mean weights of juvenile oysters by size group, date and area.*

both areas (Fig. 8). In the altered area, mortalities were above 15% during each 2-week period from 25 June to 15 October. During the same period, mortalities in the natural area ranged between 4 and 11%. The period of peak mortalities did not coincide in the two areas. The months of greatest mortalities were similar to those reported by Hofstetter (1967) on the Galveston Bay commercial reefs but his greatest monthly rate of 10% (in June 1967) was less than we observed from July to October in the altered area.

The average annual mortality rate of oysters (sizes combined) was 52.2% in the natural bayou and 91.2% in the altered canal and was greater

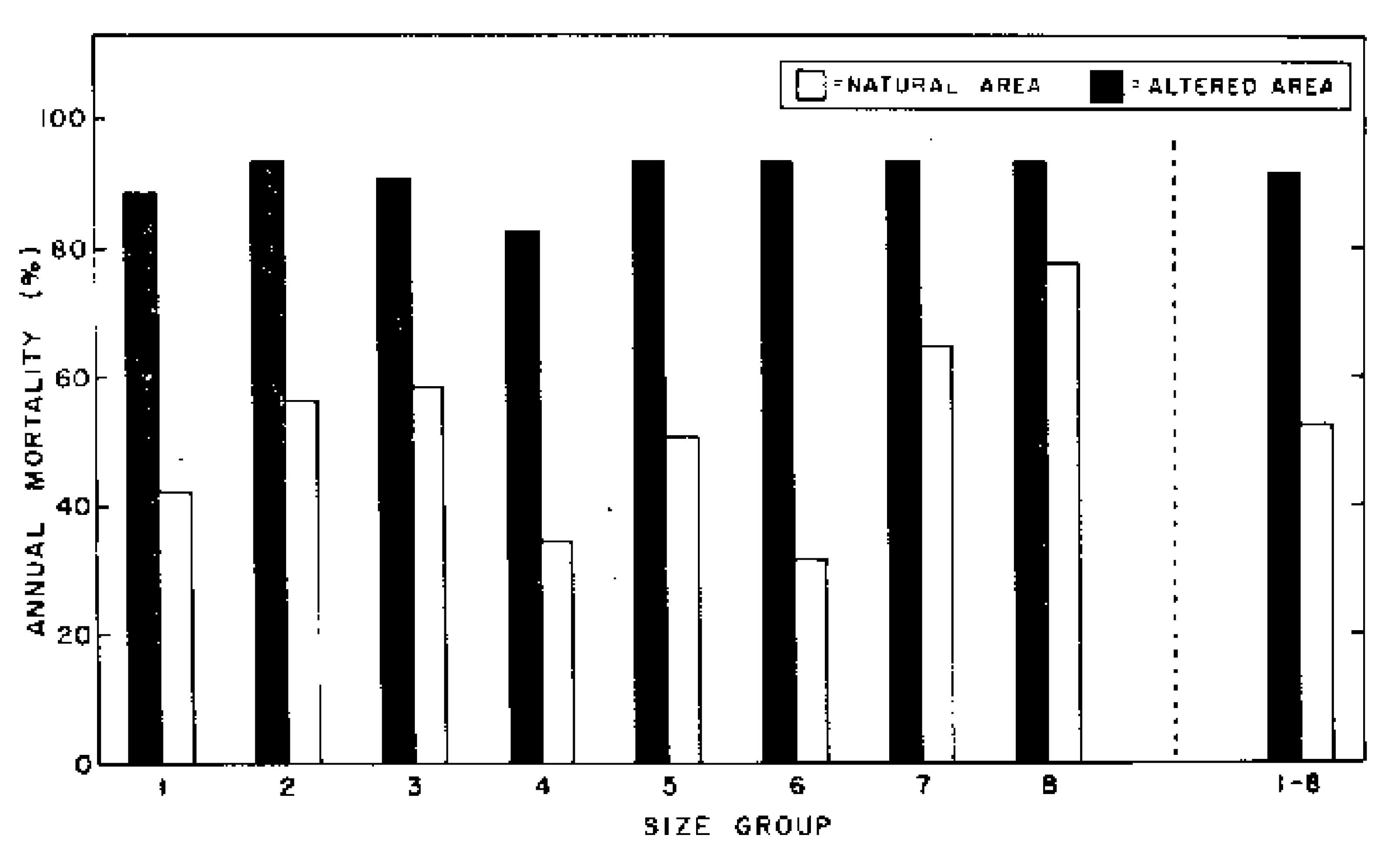

FIG. 7. *Annual mortality rates of juvenile oysters by size group and area, and for size groups combined.*

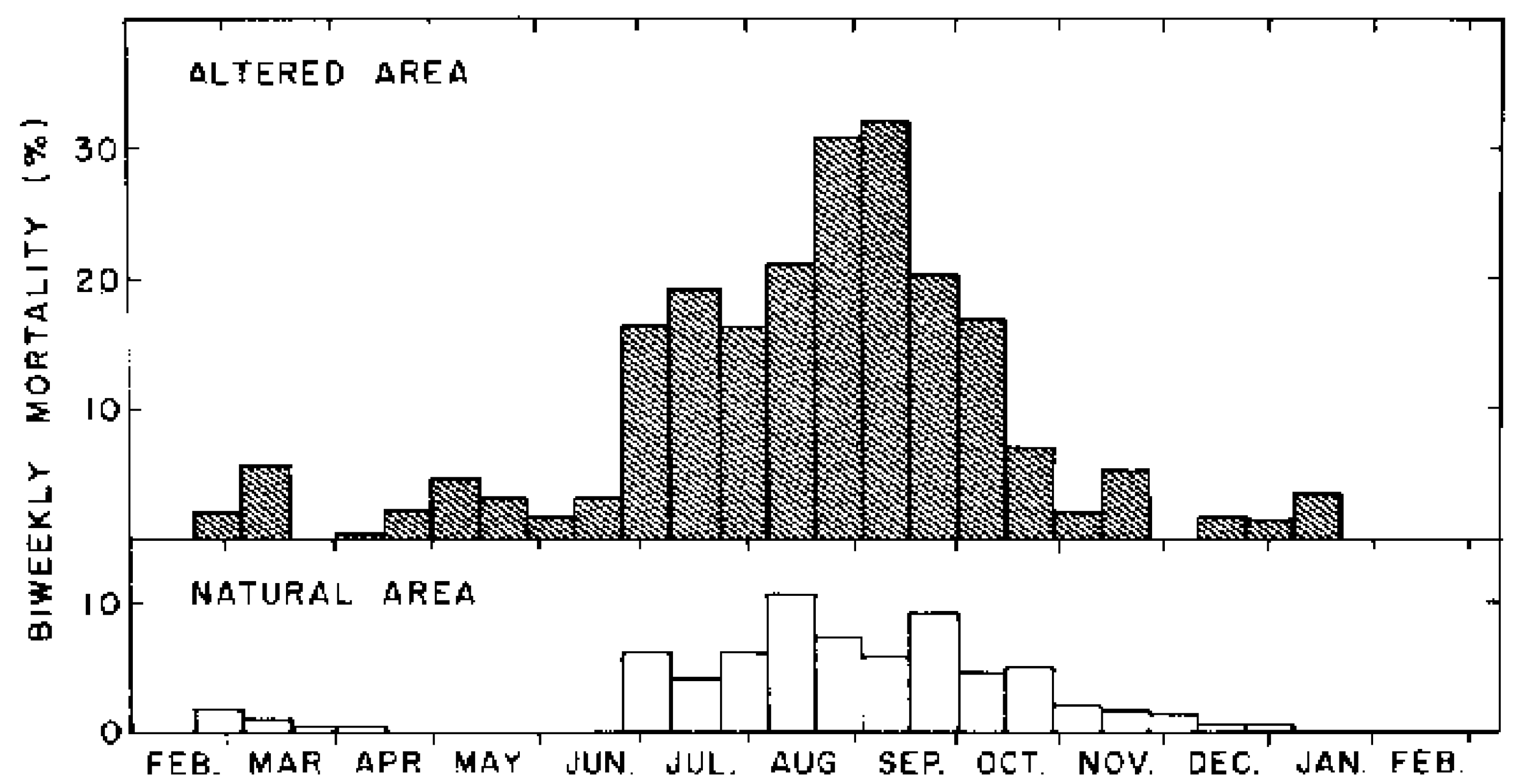

FIG. 8. *Biweekly mortality rates of juvenile oysters by date and area.*

in the canal for every size class. Mortalities on two commercial reefs in Galveston Bay during spring, summer and fall ranged from 35 to 52% during 1963-65 and from 24 to 30% in 1966, a low salinity year (Hofstetter, 1966). A tray study conducted during the same seasons on the same reefs in 1965 had mortalities of 25% for 9 months. Because only the winter, the season of lowest expected mortality, was excluded, the 9-month mortalities were probably not much below the annual rates. Assuming this, the mortalities we experienced, even in the natural bayou, were generally above those in Galveston Bay. In Louisiana, however, Mackin (1961) noted that tray studies by various authors showed that the usual annual mortality of oysters one year old or older is between 50-70% and may be as low as 30% or as high as 90%. Using these criteria, mortality in the natural area of our study was slightly below average whereas, in the altered area mortality was slightly above the high extreme observed in Louisiana.

Juvenile mortality rates were significantly and positively correlated to water temperature and salinity in both areas and to total and inorganic phosphate-phosphorus in the natural area (Table 1). Correlations to temperature and salinity were probably indirect relations. Mackin and Wray (1949, 1950) noted in Louisiana that though excessive mortalities occurred only when there were both high salinity and high temperature, high mortality did not always occur when those conditions prevailed. In Galveston Bay, when Hofstetter (1967) noted the rise and fall of mortality rates with temperature and salinity during 1967, he also reported a high incidence of *D. marinum.* The total phosphate and inorganic phosphate-phosphorus relation with mortality may be the result of over-nutrification similar to that observed on Long Island Sound in 1950-55 where a high concentration of phosphates, resulting from discharge of duck-farm wastes, occurred and caused heavy algal blooms (Wallace, 1966). In addition to high mortality, the oysters became poorer in quality and size and could no longer be marketed.

Dissolved oxygen was inversely correlated to mortality in both natural and altered areas (Table 1). Low dissolved oxygen was probably not, however, the direct cause of most of the mortality. Mackin and Wray (1949, 1950) observed that, except as part of the disease syndrome, oxygen depletion may be ruled out as a contributing factor of mortalities. In laboratory experiments, Sparks, Boswell and Mackin (1958) showed that oysters survive for several days in less than 1.0 ppm O_2; one survived 120 hr after the O_2 was reduced below 1.0 ppm. It is not clear, however, how other possible stresses (phytoplankton blooms, fish kills and fouling of the water by dead fish) associated with the low dissolved oxygen affected mortality rates.

Other factors possibly causing a higher mortality in the altered area were examined. Dying oysters were collected on 2 July, 30 July and 13 August and cutured for *D. marinum*, with negative results. This was unexpected because infections are usually prevalent each summer in Galveston Bay (Heffernan and Hofstetter, 1960; Hofstetter, 1967). Mudworm, *Polydora websteri*, blisters and boring sponges, *Cliona* sp., occurred at about the same frequency in both areas. Mussels, barnacles and bryozoans on the oysters were about equally abundant at removal time (every 2 months) between the two areas. Boring clams, *Diplothyra smithii*, and oyster drills, *T. haemastoma*, were never observed at either study site.

DISCUSSION

Setting, growth and survival rates observed during this study were much more favorable for oyster production in the natural bayou than in the small dead-end canal located in the housing development. Our study was not representative of either the entire natural marsh or altered area since we intentionally chose study locations in the upper reaches of each area, furthest from the bay. We located away from the open bay to monitor more completely the differing effects the natural marsh with its bayous and the development with its greatly altered habitat may have on the oysters. Also within the development the canals furthest from the bay were often the narrowest and were usually located in areas where most of the houses had already been built. We therefore believed that whatever impact the housing development might have on the oyster environment would be greatest at the site selected.

The standing crop of oysters in the natural bayou was low probably because of lack of suitable substrate for attachment. Therefore, production could be increased, at least during some years, by providing more substrate.

The standing crop of oysters on the bulkheads in many areas of the development was and is high. In the spring of 1969, adult oysters were more abundant than now in the development canal where station A was located. A majority of those attached above the mean low tide level died during the summer of 1969. This heavy mortality did not occur in the canals located close to the bay (Fig. 1). Indications are that environmental conditions for oyster production in the canal at station A were not as unfavorable in one or both of the previous 2 years as in 1969 because spatfall and subsequent survival were apparently more successful in at least one of the immediately preceding years.

We believe that poor setting and growth, and high mortality in the canal were caused directly or indirectly by heavy plankton blooms that occurred during the summer. During these blooms, the oxygen level decreased drastically at night, resulting in at least four fish kills from May to August. Either high concentrations of plankton, or low dissolved oxygen, or "foul" water resulting from the decaying fish, or all three, probably depressed setting, growth and survival. Previous experiments have shown that oyster feeding may severely diminish or cease altogether in either high plankton (Loosanoff and Engle, 1947) or low oxygen (Sparks *et al*, 1958) concentrations, and that some species of algae produce toxic metabolites which can kill oyster larvae (Davis, 1969). Also, the need for "nonfouled" water for good oyster production has been indicated (Galtsoff, 1964; Wallace, 1966).

Possible causes of heavy plankton blooms and resulting oxygen depletions in the upper end of the development in 1969 included poor water circulation, inadequate water exchange and high nutrient levels. Wind-driven circulation responsible for reaeration of the waters in the development is less than in the natural area because of houses blocking and diverting prevailing winds and because many of the canals are narrow and are perpendicular to the direction of prevailing summer winds. Water depths at mean low tide in the development averaged about 1.5 m but were often much greater, sometimes over 3 m, whereas depths in the natural area averaged about 0.6 m but were always less than 1 m. With the average tide level change of 0.3 m, this means that only about one-fifth of the volume of water in the development exchanges with the bay during a normal tidal cycle, whereas about one-half exchanges per cycle in the natural area. Nutrient levels were about the same (nitrogen) or slightly higher (phosphates) in the canal than in the bayou. It is possible, however, that because of reduced water exchange, nutrient levels in parts of the development are too high to maintain a balanced ecological system.

The feasibility of utilizing bulkheaded canal areas for economic oyster production appears doubtful in developments unless the canal systems are designed to insure good water circulation. Though these areas may have enough years of good oyster production to maintain a sizable standing crop, it is unlikely that the production would be consistent enough to support intensive commercial utilization.

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